

# MEASUREMENT OF THE HIGGS MASS VIA THE CHANNEL: $e^+e^- \rightarrow Z H \rightarrow e^+e^- + X$

D. Benchenkroun<sup>1</sup>, J-Y. Hostachy<sup>2</sup>, Y. Khoulaki<sup>1</sup> and L. Morin<sup>2</sup> \*

1- Université Hassan II, Faculté des Sciences Ain Chock,  
BP 5366 Maârif, Casablanca - Morocco

2- Laboratoire de Physique des Subatomique et de Cosmologie (LPSC),  
Université Joseph Fourier (Grenoble I), CNRS/IN2P3,  
Institut Polytechnique de Grenoble,  
53 rue des Martyrs, F-38026 Grenoble Cedex - France

In this communication, the mass declined for the decay channel,  $e^+e^- \rightarrow ZH \rightarrow e^+e^- + X$ , as measured by the ILD detector was studied. The Higgs mass is assumed to be 120 GeV and the center of mass energy is 250 GeV. For an integrated luminosity of  $250 \text{ fb}^{-1}$ , the accuracy of the reconstruction and the good knowledge of the initial state allow for the measurement of the Higgs boson mass with a precision of about 100 MeV.

## 1 Introduction

One of the major goals of the ILC ("International Large Collider") is to observe the Higgs boson and describe its properties. In the Standard Model [1] the Higgs particle plays a key role in explaining the origin of the masses of the elementary particles. If existing, a Higgs boson with a mass of 120 GeV is favoured by recent analyses of electro-weak data [3]. The Higgs-strahlung process ( $e^+e^- \rightarrow Z^* \rightarrow ZH$ ) is the major Higgs production mechanism at ILC, see Figure 1. In particular, in this study, we will consider the channel  $e^+e^- \rightarrow ZH \rightarrow e^+e^- + X$ .

By detecting the  $e^+e^-$  lepton pair produced by the well-known Z boson decay, one can measure the Higgs mass (using the mass recoiling of the Z) independently of the Higgs decay. The most favourable case is obtained for the center of mass energy slightly larger than the Z boson mass plus the Higgs boson mass (i.e.  $\gtrsim 211.2 \text{ GeV}$ ) [2].

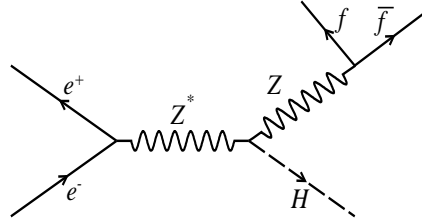


Figure 1: Higgs boson production via Higgs-strahlung process.

## 2 Event generation and detector simulation

The analysis was performed with the International Large detector (ILD) data sample fulfilled for ILD Letter of Intent [4]. The events are fully simulated and reconstructed with the

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ILD\_00 detector model. The Higgs mass is assumed to be 120 GeV, and the center of mass energy is 250 GeV, with an integrated luminosity of  $250 \text{ fb}^{-1}$ . The  $e^+$  polarization is taken to be equal to 30% and the  $e^-$  polarization is 80%.

Cross section (fb)	$e^+e^-$ beam polarization mode (30%, 80%)	
Process	(+, -)	(-, +)
ZH $\rightarrow$ eeX	12.55	8.43
ee (Bhabha)	$17.30 \cdot 10^6$	$17.28 \cdot 10^6$
4f $\rightarrow$ eeff	4897	3793

Table 1: ZH $\rightarrow$ eeX and background cross sections as a function of the beam polarization.

The cross section for Bhabha scattering is 6 orders of magnitude larger than the signal cross section.

Table 1 gives the signal (ZH $\rightarrow$ eeX) cross section as a function of the beam polarization (e.g. (+,-) mode means that the positron beam polarization is +30% and the electron beam polarization is -80%). The polarization modes (-,-) and (+,+) lead to smaller signal cross sections: 7.65 and 5.78 fb respectively for similar levels of background. The Bhabha scattering (ee) and the Standard Model events with 4 fermions, including  $e^+e^-$  contribute to the background.

### 3 Event reconstruction and background rejection

The identification of the Z boson is obtained by selecting the  $e^+e^-$  pair which gives the best mass for the Z boson. In our case:  $M_{Zreconstructed} = M_Z \pm 10 \text{ GeV}$ . In addition, central leptons with opposite charge are required, i.e.:  $|\cos(\theta_i)| < 0.9$  (in that case the momentum measurement is optimal)

(+,-)	$L_{simul}$ ( $\text{fb}^{-1}$ )	$N_{simul}$	$N_{reconst}$	$N_{expected}$ for $250 \text{ fb}^{-1}$
eeX	10 000	125 500	49 799	1 245
ee	0.5123	8 866 734	48 201	$23 \cdot 10^6$

Table 2: Number of simulated, reconstructed and expected events with their associated luminosity for the (+,-) beam polarization mode.

The Higgs mass is then calculated from the well known formula:

$$M_H^2 = s + M_Z^2 - 2M_Z\sqrt{s},$$

where  $M_Z$  is the reconstructed mass of the Z boson and  $\sqrt{s}$  the total energy in the mass center of the collision.

The expected number of events after selection is given in Table 2. Despite a worthy gain, the Bhabha effect remains strongly dominant.

### 4 The Bhabha scattering

To reject the Bhabha events, a cut on the number of reconstructed objects ( $N_{objects} > 21$ ) is applied, see Figure 2. This cut removes the first maximum in the signal distribution which probably corresponds to events where the Higgs boson decays into a  $\tau^+\tau^-$  pair. Unfortunately, the measurement of the cut efficiency is limited by the available Monte Carlo event number, see Table 3. Nevertheless, this cut looks very efficient because of the shape of the Bhabha distribution. Therefore, in the following parts the Bhabha effect will be

neglected but the cut on the number of reconstructed objects will be maintained.

$(+, -)$	$L_{simul}$ (fb <sup>-1</sup> )	$N_{objects} > 21$	$N_{objects} > 21$ for 250 fb <sup>-1</sup>
eeX	10 000	55 847	1396
ee	0.5123	1	487

Table 3: Number of events, with their associated luminosity, after the cut on the number of reconstructed objects for the  $(+, -)$  beam polarization mode.

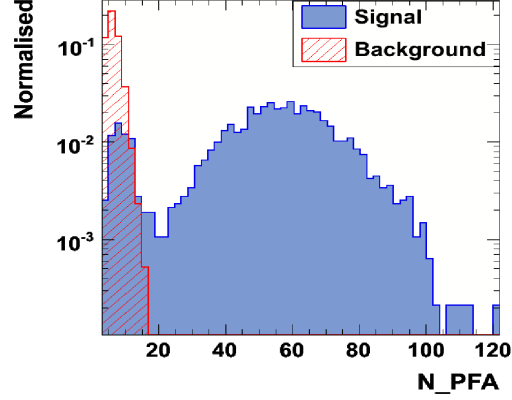


Figure 2: Normalized distributions (surfaces equal to 1) of the reconstructed objects from the Particle Flow Algorithm (PFA) [5] for the ZH signal (in blue) and the ee Bhabha scattering (in red).

## 5 Event selection (cuts on kinematic variables)

The following cuts were applied to reject the 4 fermion background:

1. the di-lepton transverse momentum calculated from the vectorial sum of the two leptons:  $18 \text{ GeV} < P_{t_{dilepton}} < 68 \text{ GeV}$ ,
2. the acollinearity (i.e. angle between the 2 leptons,  $\text{acol} = \cos^{-1}(\mathbf{P}_1 \cdot \mathbf{P}_2 / |\mathbf{P}_1| \cdot |\mathbf{P}_2|)$ ):  $0.4 < \text{acol} < 1.35$ ,
3. the energy of the Z boson:  $20 \text{ GeV} < E_Z < 115 \text{ GeV}$ ,
4. the Higgs mass interval:  $115 \text{ GeV} < M_H < 165 \text{ GeV}$ .

Different cuts are shown in Figure 3. Reconstructed recoil mass distributions before and after the selection are presented in Figure 4.

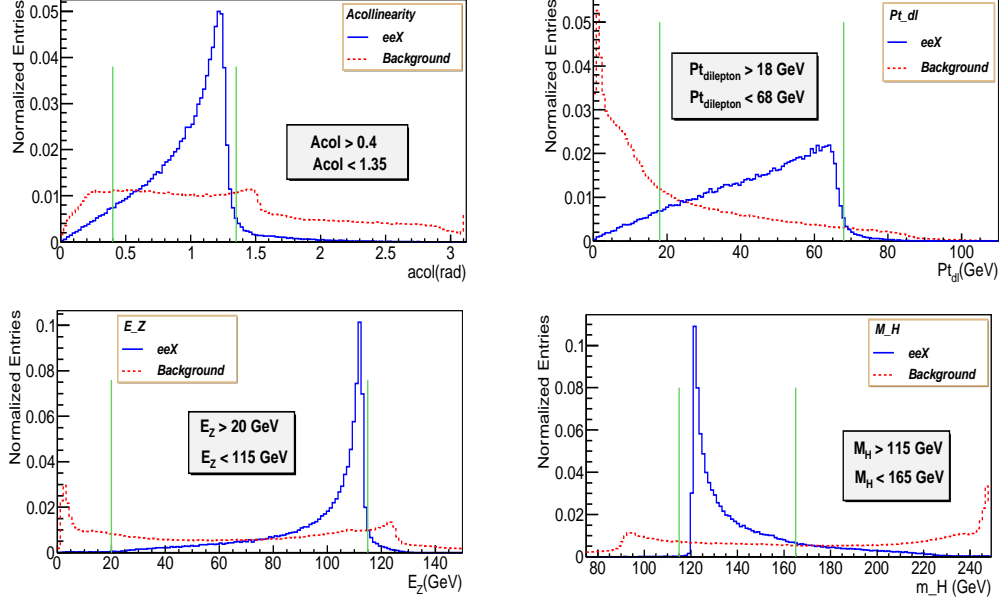


Figure 3: Event selection cuts (the distribution surfaces are normalized to 1).

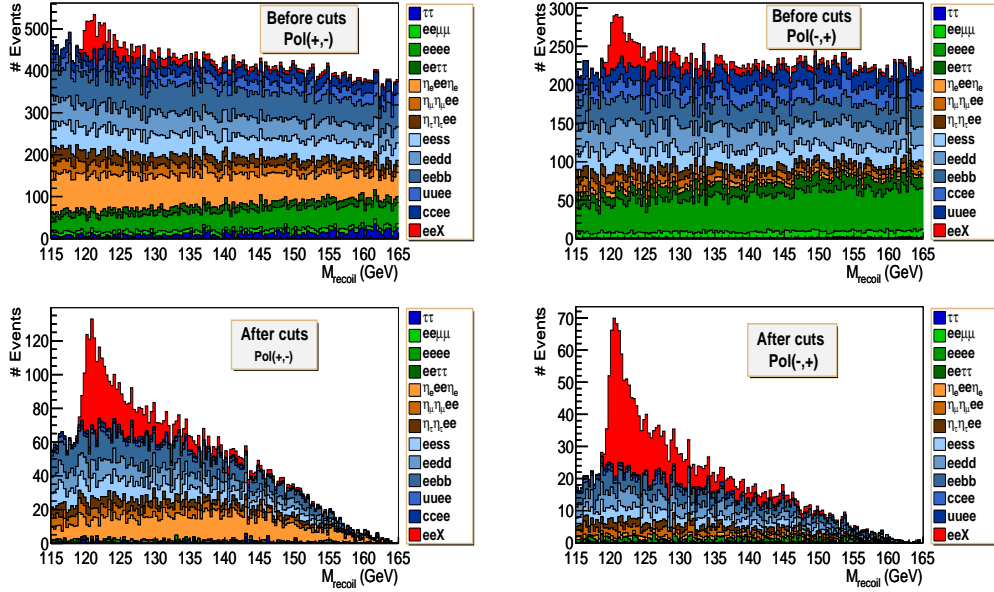


Figure 4: Reconstructed recoil mass distributions before and after the final cuts.

## 6 Reconstruction of the Higgs mass

The Higgs recoil mass distribution is fitted with a GPET function ("Gaussian Peak Exponential Tail") defined in the following way:

$$f(x; \alpha, n, \bar{x}, \sigma) = N \begin{cases} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}} & : \text{for } \frac{x-\bar{x}}{\sigma} \leq \alpha \\ \beta \cdot e^{-\frac{(x-\bar{x})^2}{2\sigma^2}} + (1-\beta) \cdot e^{\frac{\alpha^2}{2}} \cdot e^{-(x-\bar{x}) \cdot \frac{\alpha}{\sigma}} & : \text{for } \frac{x-\bar{x}}{\sigma} > \alpha \end{cases}$$

where  $\beta \in (0,1)$ . This function and its first derivative are continuous when  $(x - \bar{x})/\sigma = \alpha$ .

When the cuts are applied to reject the background, one observes a small distortion in the signal distribution in the region between 121 and 123 GeV. This can be removed by adding an additional Gaussian in the same region, as given by:

$$f'(x; \alpha, n, \bar{x}, \sigma) = f(x; \alpha, n, \bar{x}, \sigma) + N_1 G(x; \bar{x}_1, \sigma_1)$$

The parameters  $N_1$ ,  $\bar{x}_1$  and  $\sigma_1$  are determined in the fit ( $\bar{x}_1$  is around 122 GeV and  $\sigma_1$  is between 1 to 3 GeV). The corrected GPET function will be used in the following studies.

Figure 5 shows the pure signal fitted by the corrected function for the (+,-) polarization mode.

The background fits to a polynomial sum of degree 6, see Figure 6.

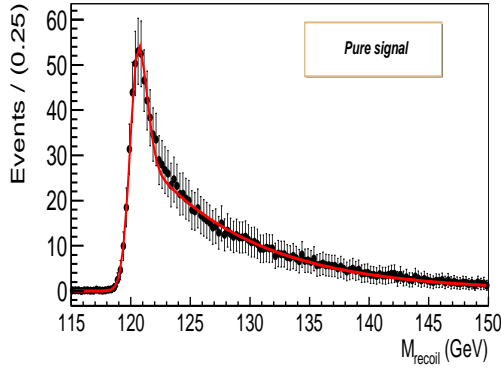


Figure 5: Fit of the Higgs recoil mass distribution with the corrected GPET function for the (+,-) beam polarization mode.

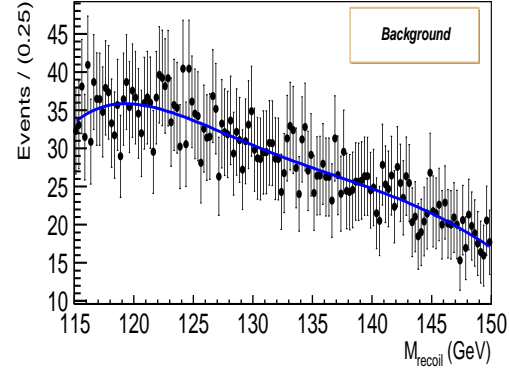


Figure 6: Fit of the background distribution with a polynomial sum for the (+,-) beam polarization mode.

## 7 Measurement of the Higgs mass with signal and background

Figure 7 shows the Higgs recoil mass distributions (signal + background) for different beam polarization modes. Some of the fit parameters are given in Table 4. The accuracy on the Higgs mass measurement is around 100 MeV.

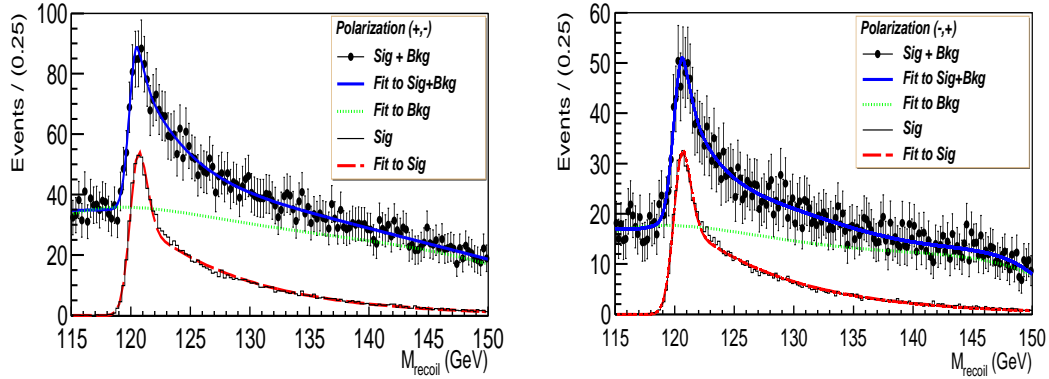


Figure 7: Fits of the Higgs recoil mass distributions (signal + background) for different beam polarization modes.

	$e^+e^-$ beam polarization mode (30%, 80%)			
	$(+,-)$		$(-,+)$	
	Only signal	Signal + Bkgrd	Only signal	Signal + Bkgrd
$M_H$ (GeV)	$120.486 \pm 0.073$	$120.368 \pm 0.100$	$120.507 \pm 0.085$	$120.445 \pm 0.110$
$\sigma$ (GeV)	$0.638 \pm 0.051$	$0.575 \pm 0.083$	$0.654 \pm 0.062$	$0.592 \pm 0.100$

Table 4: Fit parameter results of the Higgs recoil mass for different polarization beam modes.

## 8 Conclusion and outlook

The measurement of the Higgs mass recoil in the channel:  $e^+e^- \rightarrow Z H \rightarrow e^+e^- + X$  illustrates the ILC potential for accurate measurements. The effect of the background is to deteriorate the accuracy on the Higgs boson mass. For  $M_H = 120$  GeV and a luminosity of  $250 \text{ fb}^{-1}$ , it was found:

$M_{Rec} = 120.368 \pm 0.100$  GeV, for the beam polarization mode (+,-) and

$M_{Rec} = 120.445 \pm 0.110$  GeV, for the beam polarization mode (-,+).

The Higgs recoil mass distribution is asymmetric. This could be, for instance, partially corrected by taking into account the bremsstrahlung photons emitted in the ILD detector and by using the electromagnetic calorimeter and other sub-detectors. This is the next step in the analysis.

For more information please refer to [6, 2].

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